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# Developing a Vision of Pre-College Engineering Education

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**Abstract**

We report the results of a study focused on identifying and articulating an "epistemic foundation" underlying a pre-collegiate focus on engineering. We do so in the context of UTeach*Engineering* (UTE), a program supported in part by funding by the National Science Foundation and designed to develop a model approach to address the systematic challenges facing this work—from identifying learning goals, to certifying pre- and in-service teachers for engineering courses to developing a research-based high school engineering course. Given the systemic nature of the UTE approach, this model is positioned to serve as a starting point to further the conversation around two of the National Academy of Engineering Committee on Standards in K-12 Engineering Education (2010) central recommendations for future work in this area: (1) Identification of core ideas in engineering, and (2) creation of guidelines for instructional materials. Toward that end, project faculty and staff were interviewed and/or surveyed about their views on the goals and outcomes of engineering and engineering teacher education, as well as strategies design to reach these goals and the warrants for them. Data were analyzed following a grounded protocol. The results align well with previous efforts to identify "core engineering concepts, skills, and dispositions for K-12 education" (National Academy of Engineering Committee on Standards in K-12 Engineering Education, 2010, Annex to Chapter 3).

*Keywords:* teacher preparation, high school course

## Background and Significance

The National Academy of Engineering and National Research Council Committee on K-12 Engineering Education (2009) estimates that several million students participated in formal engineering coursework at the K-12 level between 1994 and 2009. Much of this coursework was elective or classified as vocational or technical instruction, but increasingly engineering is taking a place in the standard STEM education sequence. In a recent study, 18 of 42 state supervisors indicated that engineering education was included explicitly in their state frameworks, and the same percentage indicated that the frameworks for their states contained "STEM education that includes technology and Engineering" (Moye, Dugger, & Starkweather, 2012, p.26). In Texas, for example, when high school graduation requirements were increased from three to four years of science under the standard plan[1], Engineering Design and Problem Solving was approved as one option for the final course in the sequence. This fourth-year course has introductory physics, chemistry and biology as prerequisites and expands the inventory of elective engineering courses already available (Texas Education Agency, 2009).

Engineering is also represented in the proposed Next Generation Science Standards (NGSS), which include "a commitment to fully integrating engineering and technology into the structure of science education by raising engineering design to the same level as scientific inquiry in classroom instruction when teaching science disciplines at all levels, and by according core ideas of engineering and technology the same status as core ideas in the other major science disciplines" (Achieve, 2012). Should they be broadly adopted in a version close to the current draft, the NGSS, may begin to address one of the major problems facing pre-college engineering education as identified by Chandler, Fontenot, and Tate (2011): the lack of the lack of broadly accepted national K-12 engineering standards and a shared understanding of the role of engineering in pre-college education. However, other needs identified by those authors remain, including the lack of systemic infrastructure, e.g., programs designed to prepare pre-college engineering teachers, cooperative partnerships between post secondary and pre-college institutions; and, perhaps hardest to remedy, the lack of an "epistemic foundation and tradition" for engineering education in the US (p. 40). In short, we, as a community of educators and researchers, still lack a shared vision of pre-college engineering education:

- What are its goals, i.e., are we creating future engineers, supporting general engineering literacy, akin to scientific literacy, and/or teaching math and science content through engineering?
- Who are the teachers and how are they trained?
- Who are the students and what outcomes do we expect for them?
- How can we work systemically, i.e., across all components of the educational system, to enhance pre-college engineering education capacity?

This paper presents the goals, measurable outcomes, and commitments that the UTeach*Engineering* project has developed in response to the above open questions. We present these as a proposal to the community as we move forward in developing pre-college engineering education and teacher education infrastructure. UTeach*Engineering* was proposed and funded "to meet the growing need for engineering teachers in Texas, and to serve as a model in engineering [teacher] education across the nation" with a goal of reaching a diverse population of teachers (directly) and students (indirectly) (UTeach*Engineering* Project, n.d)[2]. Progress is being made toward the first goal: a new engineering certification has been established, and UTeach*Engineering* is now producing graduates with this certification at a projected rate of three per year. An average of 10 in-service high school teachers are now receiving masters degrees in engineering education annually, and, as of 2011, 91 teachers have attended summer institutes across the state. Studies of these teachers have shown that UTeach*Engineering* has been successful in improving their basic engineering knowledge in mechanics and reverse engineering and their understanding of the design process, and in changing teacher practice (Martin, Ko, Benton, Farmer & Allen, 2010; Martin, Ko, Peacock & Rudolph, 2011). Research on program efficacy is ongoing.

The second purpose of the UTeach*Engineering* project, providing a national model, requires multiple steps: (1) Articulation and refinement of the goals and expected outcomes of pre-college engineering education and teacher education, (2) evaluation of program success in reaching those goals and outcomes, and (3) dissemination of these products. As the project evolved and began interacting with the educational system at many levels, the project's vision of engineering education also evolved. As one PI stated, our goals became "overlapping" as opposed to "shared"—revealing the complexity underlying our assumption of shared project-wide goals and commitments. Moreover, even clearly articulated goals merit unpacking and analysis at a fundamental level. Articulating a coherent process for preparing and supporting secondary engineering educators and contributing to an understanding of the program process and product is now one of the stated deliverables of the NSF-funded project, and was the impetus for the study reported here. Our approach was to facilitate the articulation and unpacking of the program goals and expected outcomes through a qualitative research effort. This study is designed to describe (1) the program context and components, (2) the clarified vision of engineering and engineering teacher education, including goals and intended participant outcomes developed under its auspices, and (3) the warrants or justifications behind these goals and outcomes, including the commitments on the part of program personnel that led to their adoption. As noted above, additional research is underway to evaluate the strategies developed to meet these goals.

The study was intended to further the objective of providing a model for pre-college engineering and engineering teacher education. These results are not intended to be taken as a definitive statement about what engineering education should look like, but as a 'straw man' proposal developed in conjunction with engineering professors, learning scientists, school district administrators, teachers, and practicing engineers, a starting point for discussion in the larger community.

## Study Context

In response to the increased emphasis on pre-college engineering, and as a natural outgrowth of its integrated stance with regard to science and mathematics learning and teacher preparation, the UTeach secondary teacher

[1] The Texas Education Agency identifies a 'minimum' program, which requires two years of science, a 'recommended high school program,' which requires four years of science, and a 'distinguished achievement-advanced' program. See http://ritter.tea.state.tx.us/rules/tac/chapter074/ch074f.html

[2] We distinguish between the NSF-funded UTeach*Engineering* project and the permanent UTeach*Engineering* program it helped to develop.

preparation program expanded to explicitly include engineering. The program, currently being replicated at 23 institutions nationally (National Academy of Sciences, 2006; UTeach website, n.d.), now prepares teachers for the Mathematics/Physical Science and Engineering certification that has recently become an option in Texas.

In 2008, the University of Texas was awarded a $12.5 million Math and Science Partnership (MSP) grant from the National Science Foundation to develop engineering education infrastructure, including an engineering strand embedded within the University of Texas UTeach pre-service program, a master's degree program in engineering education, and an annual professional development institute for in-service teachers. Collectively known as UTeach*Engineering*, these new initiatives build on long-standing teacher professional development and outreach efforts in engineering at the University of Texas, such as the DTEACh program (Crawford, Wood, Fowler & Norrell,1994). DTEACh has provided professional development workshops for more than 1,000 pre-college teachers (ultimately reaching over 85,000 students originally at the elementary level and later secondary) to enhance their understanding of design and explore ways to confidently incorporate design into their existing mathematics, science, and social studies curriculum in both formal and informal learning environments (DTEACh website, n.d.).

UTeach*Engineering* is a collaboration between schools and colleges of engineering, natural sciences, and education at the University of Texas. The program works systemically, i.e., effecting change at all levels of the educational system from university faculty, students and administrators, to local school districts, to state and national agencies, to promote engineering education. It has a primary emphasis on pre-college engineering curriculum development and engineering teacher development, both pre-service and in-service. The major components of the program are described separately below.

### *High School Course*

The UTeach*Engineering* project is developing, piloting and refining a model (exemplar) year-long high school engineering course that can be deployed at low cost in a variety of high school settings. This course is currently in its third year of pilot enactment. The UTeach*Engineering* model course will serve as a fourth-year science course in Texas. A detailed description of the course and the design principles on which it was based is given in Berland (2012).

### *Pre-service Program*

The nationally recognized UTeach secondary teacher preparation program is now incorporating engineering design activities into its suite of courses for pre-service teachers (Marshall, 2012). This continues a tradition of including design challenges in our project-oriented curriculum, such as designing an elbow (Penner, Lehrer & Schauble, 1998) and reverse engineering of a flashlight. Undergraduate and post-baccalaureate students at the University of Texas are recruited for the Mathematics/Physical Science/Engineering (Grades 8–12) certification. UTeach*Engineering* recruitment has focused primarily on introductory courses for engineering majors, such as physics and mathematics. Students are invited to enroll in recruitment courses, for which tuition is rebated, that engage students in practicing and reflecting on inquiry-based STEM teaching and allow students to evaluate whether a teaching career might be a good option for them. Scholarships of $10k per year have been available during the duration of the NSF grant to students who commit to the Mathematics/Physical Science/Engineering certification. Our first graduates were granted this certification in 2011.

### *Engineering Summer Institute for Teachers*

The Engineering Summer Institute for Teachers (ESIT) has been held at the University of Texas, Austin, annually since 2009. In addition, two replication sites have sponsored ESITs at other Texas universities. At UT Austin, the ESIT is an extremely intensive six-week, 8-hour-per-day course of work equally balanced between developing engineering design and engineering pedagogical content knowledge (knowledge for teaching engineering at the K-12 level). The engineering design portion is equivalent to a graduate engineering course (Design of Machines and Systems), and focuses heavily on reverse engineering, a robotics design challenge, a vehicle design challenge, and an open-ended final design challenge. In 2011, the final design challenge involved either reverse engineering or the design of an aerial imaging system. The pedagogical content portion of the ESIT focuses on recent research in design-based and project-based instruction, development of activities to familiarize students with engineering careers, practices and habits of mind, equity issues in engineering education, and engineering education standards and research. In addition, in 2011 teachers engaged in a design challenge from the UTeach*Engineering* model high school curriculum.

### *Master of Arts in Science Education- Engineering (MASEE)*

UTeach*Engineering* also offers a Masters of Arts Degree in STEM Education (Engineering concentration) for in-service teachers. In this degree program, teachers are on campus each of three consecutive summers, engaging in three graduate courses each summer, as well as online courses during the two intervening academic years. The courses satisfy the requirements for a Masters of Arts in STEM Education focused on engineering education. Three of the courses are from the graduate engineering catalog, especially selected for their relevance to the pre-college engineering teacher. The other courses include Knowing and Learning in STEM and Curriculum History and Development in STEM. In addition, students complete nine hours of independent research, concluding in a report. The first cohort of eight students graduated in Summer 2011.

### *Engineering Education Infrastructure*

A final component of UTeach*Engineering* comprises our efforts to make engineering education and pre-college engineering teacher preparation ongoing core commitments at the University of Texas. Toward that end, two positions dedicated to engineering education research have been created, one in the College of Education and one in the University of Texas Cockrell School of Engineering, and a search is underway to fill these positions. Further, the program is working to institutionalize engineering education at the pre-college level in Texas, not only by creating model high school curriculum, but also by developing certification routes. UTeach*Engineering* project investigators and staff supported the Texas Education Agency in the recent creation of the Mathematics/Physical Science/Engineering (Grades 8–12) certification for high school teachers.

## Approach

In order to identify and unpack the explicit and implicit goals, outcomes, and commitments driving the UTeach*Engineering* team's efforts in developing a coherent and achievable approach to pre-college engineering education, the first author and a team of researchers examined existing documentation and other artifacts that had been generated by the project, conducted thirteen individual interviews of project personnel, and facilitated and recorded team meetings dealing with the study questions. In addition, five project investigators and staff members submitted written surveys. Finally, we examined all standards, guidelines, and other publications cited by project personnel in interviews or surveys as having guided the development of UTeach*Engineering*, either explicitly or implicitly (see Table 1).

The interviews were transcribed and the transcripts and other artifacts were coded following a grounded qualitative methodology (Corbin & Strauss, 1990). Data were reviewed and coded for emergent concepts as they were collected, so that the preliminary results informed subsequent data collection. The emergent concepts were grouped into categories to build a theory (description and explanation) of the phenomenon of interest—in this case, K-12 engineering curriculum and teacher preparation—without regard to any pre-existing theoretical framework. In other words, no set of standards (either from the literature or any other source) was used as an absolute measure against which to judge the emerging concepts. Two independent coders coded the initial interviews and then negotiated a common set of designations for the emergent concepts. Three independent coders then used this common set of designations to code a sample subset of all the interviews. Agreement between the three coders was above 90%, indicating that the designated categories comprised a reliable characterization of the artifacts. This set of categories was then used to code the entire archive of

Table 1
Publications Cited as having Guided the Development of PROGRAM

| Document | Citation |
|---|---|
| Engineering in K-12 Education | National Academy of Engineering and National Research Council Committee on K 12 Engineering Education. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects.* Downloadable from http://www.nap.edu/catalog.php?record_id=12635 |
| The Next Generation Engineer | Peerman, Allyson (2010). Austin Forum on Science, Technology & Society Presentation The next generation engineer. Austin, TX: Advanced Micro Devices. |
| NSF Site Visit Report | NSF site visit report for Math Science Partnership project, award DUE 0831811. |
| Standards for K-12 Engineering Education? | National Academy of Engineering Committee on Standards in K-12 Engineering Education. (2010). *Standards for K-12 engineering education?* Downloadable from http://www.nap.edu/catalog.php?record_id=12990 |
| Why So Few? | Hill, Catherine, Christianne Corbett, & Andresse St. Rose (2010). Why so few? Women in science, technology, engineering and mathematics. Washington, DC: AAUW. Downloadable from http://www.aauw.org/learn/research/upload/whysofew.pdf |
| Changing the Conversation | National Academy of Engineering Committee on Public Understanding of Engineering Messages (2008). Changing the conversation: Messages for improving public understanding of engineering. Downloadable from http://www.nap.edu/catalog.php?record_id=12187 |
| Texas Essential Knowledge and Skills for the Engineering Design and Problem Solving Course | Texas Education Agency. (2009). Chapter130.373. Engineering design and problem solving. Texas essential knowledge and skills. Retrieved from http://ritter.tea.state.tx.us/rules/board/adopted/0709/ch130o-two.pdf |
| Research University Dept of Mechanical Engineering Educational Objectives and Program Outcomes | (Department website) |

project artifacts as well as standards and other publications that had been referenced as resources in the interviews.

The coding results were presented at team meetings for feedback, where they were debated, refined, and compared to the list of stated goals for the project. A final version was presented to the PIs and key staff for validation. In the next section, we present the framework guiding our approach to developing a high school engineering education program (our commitments), the goals we have set for pre-college engineering education, and the outcomes for engineering education and engineering teacher education by which our success will be measured.

## Results and Discussion

### *Commitments*

In the process of problematizing and debating goals and learning outcomes for engineering education endorsed and practiced by UTeach*Engineering*, the need to articulate the underlying commitments that served as a framework for decision making within the program became clear. These would serve as the ultimate arbiter in the debate between various program constituencies and perspectives. All program strategies and approaches were assessed against these fundamental commitments; they were the drivers for our goals, although not goals in and of themselves. The themes shown in Table 2 arose as we analyzed the interviews and other data. They classified in a category of fundamental commitments for the program--inputs or "givens" that served as the basis for designing the program and informing its subsequent priorities. Exemplar quotes are given for each.

#### *Commitment to engineering practice (Design and habits of mind)*

Central to the UTeach*Engineering* approach to engineering education is the expectation that students–both high school students and teachers in the program–will learn engineering through engineering design challenges. This differs from some more traditional approaches to engineering education that foreground science and math content and problem solving (Tate, Chandler, Fontenot & Talkmitt, 2010).

The commitment to design on the part of key project personnel is longstanding and based on extensive experience. One project faculty member was hired at the University of Texas to "teach design and do research on design" (Faculty, Mechanical Engineering, interview). Design, in particular reverse engineering of existing technology, has been central to the DTEACh program since its inception (Crawford, Wood, Fowler & Norrell, 1994). Quotes that exemplify the emphasis on engineering design include:

- "You've got to have design. Everyone agrees." (Faculty, Mechanical Engineering, interview)
- "[The primary goal is] [t]o understand the design process." (Faculty, Chemical Engineering, interview)

The commitment to engineering design is manifested in the UTeach curriculum, which has always been envisioned as culminating in project-based instruction (Marshall, Petrosino & Martin, 2010; Petrosino, 2004). When applying this pedagogical commitment in engineering classrooms, the projects are rendered as design challenges (Berland et al., under review; Harris, Martin, Roselli, & Cordray, 2006; Martin, Rivale, & Diller, 2007; Pandy, Petrosino, Austin, & Barr, 2004; Svihla, Petrosino, Martin & Diller, 2009).

We additionally see a focus on design throughout the high school curriculum, in which each unit is a unique design challenge that students address by engaging in the UTeach*Engineering* engineering design process (Guerra et al., 2012). In fact, the first principle that guides the development of the high school curriculum is contextualizing all student work within STEM design challenges. An additional principle states that each unit will use the engineering design process as an instructional framework, such that students will go through the design process in each unit. Sample challenges include designing a pinhole camera that will take a picture of an object from a particular distance; creating a "satellite camera" in which students will design a mechanism to lift a digital camera to a specified height and control its descent while it takes pictures; and designing wind turbines to optimize energy output given particular wind conditions.

This emphasis on engineering design mirrors a shift away from 'engineering science,' the result of Sputnik-era

Table 2
Underlying Commitments that Support the Development of the PROGRAM Approach to Engineering Education

| Programmatic Commitments |
|---|
| Engineering education should engage both students and teachers in engineering design and develop engineering habits of mind. (*Commitment to Engineering Practice*) |
| Research should be central to and should inform the program. (*Commitment to Research*) |
| Engineering education should strive to include, value, and enable learners of all kinds. (*Commitment to Equity*) |
| Engineering education should be interdisciplinary and involve collaboration between STEM educators, education researchers, and engineers. (*Commitment to Interdisciplinary Collaboration*) |
| Engineering education and teacher preparation should promote awareness of engineering and its relevance to society. (*Commitment to Engineering Literacy*) |

revival of science and technology viewed as scholarly, humanist endeavors, toward engineering as a creative activity necessary for global competitiveness that has been identified in the literature and adopted by other programs (Tate, Chandler Fontenot & Talkmitt, 2010). In addition, the focus on design aligns with the goals and expectations for K-12 engineering education that emerged out of the NAE and NRC's synthesis of the research (NAE and NRC Committee on Engineering in K-12 Education, 2009).

In addition to emphasizing design, the commitment to engineering practice specifies an emphasis on engineering habits of mind. This focus grows out of our vision of going beyond educating future engineers, to supporting technological literacy and enhancing learning in other STEM fields. As such, we focus on engineering habits of mind—such as systems thinking, innovation and team work—over technological skills and deep exploration of math and science concepts that are traditionally associated with engineering:

- "That's the reality of the engineering workplace. You work in groups to solve problems together." (Faculty, Mechanical Engineering, interview)
- "To me the most valuable thing is we teach them how to tackle a problem like an engineer." (Faculty, Mechanical Engineering, interview)
- "To recognize that they can have the skills to think systematically about designs that their students will come up with and be comfortable with the generic tools and not feel that there is only a single answer. Yes, the math has to be right. The science has to be right." (Faculty, Chemical Engineering, interview)

This focus on habits of mind is apparent in the high school curriculum. In particular, while STEM concepts are introduced on an as-needed basis, engineering habits of mind are carefully introduced, scaffolded, and practiced throughout the yearlong course. For example, collaboration is the focus of the third unit, which includes numerous discussions regarding the makeup of teams and how to work together. Collaboration is then practiced for the rest of the year, in the context of challenges that can only be solved in teams of four or more students.

The focus on habits of mind over particular processes or skills aligns with a shift in the scientific education community in which we see students increasingly engaging in the practices of science over memorization of facts (Lehrer & Schauble, 2006). In addition, the engineering habits of mind are identified as a core curricular goal by the National Academy of Engineering and National Research Council (NAE and NRC Committee on Engineering in K-12 Education, 2009).

*Commitment to research*

The commitment to research is fundamental to the program. Therefore, all UTeach*Engineering* educational materials—high school and teacher curriculum—are designed to align with best practices as identified in research literature. In addition, the project follows the tenets of design-based research (Design Based Research Collective, 2003; Sandoval & Bell, 2004), such that we develop theory regarding how people learn in pre-college and professional development engineering settings as we simultaneously improve upon the curriculum being developed. In particular, two of the project co-PIs are education researchers with a focus on engineering education and the project has devoted considerable resources to research its various components. This commitment is apparent in the following quotes:

- "With all these I include evaluation, research, evaluating that research and making changes as we go along." (Faculty, Chemical Engineering, interview)
- "Third [goal], is somewhat more obscure, but it involves advancing the state of the art of learning." (Faculty, Biomedical Engineering, interview)
- "And document the extent to which what we've done really is based on best practices and research findings." (Faculty, Mechanical Engineering, interview)
- "[T]o me top is to do research that contributes, that uses this unique opportunity of having high school engineering in Texas, creating the curriculum for it, … so to use that very unique context to deliver results on what is learning in engineering that we can't really answer in any other context." (Faculty, STEM Education, interview)
- "The potential separation of content from learning theory/learning sciences needs constant attention in my opinion." (Faculty, STEM Education, survey)
- "[The curriculum is based on]…the research we have done on challenge based instruction in other areas…" (Faculty, STEM Education, interview)

The high school curriculum itself reflects this commitment to research through both the design-enact-revise iterative development process the team is following and the use of learning sciences research to identify best practices. For example, the design principles the team constructed to guide the curriculum development (Berland, 2012) build off of work in the learning sciences that reveals the importance of and strategies for creating a constructivist learning environment. These principles include always engaging students in complete and sensible forms of engineering practices, and ensuring that focal science and math concepts are necessary for students' successful completion of the design projects. For example, in a pinhole camera unit students will be reminded of (or learn for the first time) relevant physics and geometry concepts, such as the properties of similar triangles, in order to determine the placement of the film and size of the pinhole for their cameras. Similarly, early in the course students will co-construct the engineering design process with their teacher rather than being told to follow specified steps.

The project team's commitment to educational research in engineering education aligns with a central need in the field. As observed by Chandler, Fontenot and Tate (2011), engineering education research often focuses on the results of particular programs without exploring "practical questions" (p. 42). The NAE and NRC synthesis of research in K-12 engineering education similarly concludes that this work is "still in its infancy" (p. 149).

*Commitment to equity*

The commitment to equity in education has been an essential element of the UTeach program since its start; UTeach graduates are required to demonstrate proficiencies in the area of equity and inclusive design (UTeach website, n.d.). Equity has been and continues to be a central research focus of project faculty and staff (Marshall, 2004; —, 2008; Marshall & Buckingham, 1995; Riegle-Crumb & King, 2010). As such, considerations of diversity and how to implement engineering education in a manner that did not disadvantage any group of students have been central to the design of our program. This commitment is exemplified in the following quotes:

- "Getting different students interested in technology. Absolutely. No question." (Faculty, Mechanical Engineering, interview)
- "The reverse engineering…we built that around a product that probably more women than men use: the hair dryer. I in particular agonized over that. We had lots of discussions about it. They are ongoing discussions. I asked the women in my senior design class to give me examples of products that they were interested in. The teachers really like it. One of the comments we kept hearing was they were the experts on that problem [hair dryer]. It gave them the experience of being in that role. They [women] were the expert users." (Faculty, Mechanical Engineering, interview)
- "We discussed, if you are going to do reverse engineering in your high school class, how do you choose products to do that. That [diversity] should be one of the considerations. It's broadly within the concept of 'It should be interesting to the students.'" (Faculty, Mechanical Engineering, interview)
- "[Our goal is to] recruit and admit to ESIT and MASEE programs teacher participants from a geographically distributed set of schools serving diverse student populations." (Staff, survey)

At the high school level, this commitment to equity requires that high schools with a range of resources be able to enact our curriculum. As such, one focus of the high school curriculum development is to make it possible to implement the curriculum with low cost. As argued by Chandler, Fontenot and Tate (2011), high school engineering curriculum is often prohibitively expensive. We avoid this problem by designing the curriculum to maximize its use of equipment, materials, and technology that are required by state standards in other science and math courses (and that schools should have on hand for other purposes), as well as less expensive equipment and supplies that are widely available for purchase at common discount retailers. Names of suggested suppliers are included in the curriculum. We ensure that any proprietary equipment will be used repeatedly throughout the course.

Further, although UTeach*Engineering* will distribute exemplar design challenges, teachers will be free to generate their own modules that are aligned with the needs, interests, and experiences of their students. To support this flexibility, the curriculum team has created a curriculum framework that identifies the key engineering concepts and practices that will be introduced in each unit (Berland, 2012). This is meant to ensure that these core ideas are scaffolded appropriately throughout the year. Using this, teachers and designers can create their own contexts that will fit within the scaffolding sequence. This mirrors the approach taken by the T-STEM Center of Texas Tech University:

> *Instead of developing an engineering curriculum tied to certain equipment or specific science and mathematics content …to develop the TTU engineering design FRAME model, which provides teachers with tools to manage design projects and use project lifecycle conventions for documentation and various project phase activities to assess and evaluate student learning, as well as a framework to teach course content (Chandler, Fontenot, & Tate, 2011, p. 45).*

In addition, the design challenges are structured to appeal to a wide range of students. In particular, given recent research supporting the idea that students will be more readily interested in design challenges that foreground societal problems (e.g., Busch-Vishniac & Jarosz, 2004; Mayberry et al., 1999; National Academy of Engineering Committee on Public Understanding of Engineering, 2008), our curriculum frames the exemplar challenges developed to date in terms of a societal need. For example, students discuss the necessity of (and problems caused by) satellite cameras; a wind turbine challenge is motivated by a discussion about their use to transport water to rural villages. The framework, however, recognizes that not all students will be compelled by all societal needs and allows for customization. Calabrese-Barton (2003) has shown the importance to urban students of designing and creating physical objects for their personal use and ownership as opposed to those that might fill a broader community need.

Finally, a range of engineering disciplines are highlighted such that students that are not intrigued by traditional mechanical and electrical engineering tasks can experience other possibilities and see examples of non-traditional engineers. For example, in the ESIT, a key theme is 'All kinds of engineers.' Modeling a project that teachers might enact with their high school students, each participant researches one engineering discipline, its relevance to society, and a representative of that discipline from an under-represented group. Participants present their findings, highlighting how the given discipline interacts with the design challenges incorporated into the ESIT curriculum.

*Commitment to interdisciplinary collaboration*

This commitment derives from the longstanding UTeach commitment to interdisciplinary teacher training. Long experience with elementary teachers in the DTEACh program and the Engineering Summer Institute for Teachers has also demonstrated the value of preparing non-engineering teachers to incorporate elements of design into their own courses. In addition, this commitment is an extension of the UTeach*Engineering* commitment to equity: as we work to foster interest in engineering from a broad range of students, we must represent the broad range of ways in which individuals can engage in this field, from practice to research to teaching. Quotes that exemplify this commitment to interdisciplinary collaboration include:

- "[We really need to have] a day a month when we could all sit together and have these discussions." (Faculty, Chemical Engineering, interview)
- "The various meetings that are held in a regular way amongst the professional members of UTeach*Engineering* and contribute to [advancing the start of the art of learning]." (Faculty, Biomedical Engineering, interview)
- "That's the fun part. That's what would have been fun about doing it together." (Faculty, Mechanical Engineering, interview)

This commitment is made most obvious in the project leadership of UTeach*Engineering*: it includes engineers and engineering professors from a range of disciplines (Mechanical, Chemical, Biomedical), professors of education, master teachers, and school district administrators. In addition, the commitment to interdisciplinary collaboration is apparent in the academic structure of our university in which the Science and Mathematics Education Graduate Studies Committee has recently converted its science and mathematics education programs into a unified STEM education program. This action is in recognition that (1) the STEM fields are collectively considered core technological underpinnings of an advanced society, according to both the National Research Council and the National Science Foundation, and (2) for over a decade our program has sought a much more integrated model for STEM education instruction, service, and research. Our faculty publish and receive external funding in all four areas and our philosophical position is much more consistent with an integrated approach than a separate subject area approach in each area (Petrosino, 2012)

*Commitment to engineering literacy*

Although the goal of promoting engineering for citizens (non-engineers) was ultimately identified as being a secondary objective of the immediate NSF funded project, it was a recurring theme among the warrants for our goals and expected outcomes and arose as a significant theme in interview data. It relates to our commitment to diversity in seeking to provide access to technological competence and understanding to a broad range of citizens, not just those trained and working as engineers. It is exemplified in the following quotes:

- "This is something that can impact on the way we think about things as citizens, on the way we think about problems in our daily lives." (Faculty, Chemical Engineering, interview)
- "Another important point of view is someone who won't become an engineer but who will be out in society influenced by the technologies that engineers create." (Faculty, Chemical Engineering, interview)
- "One of our functions for people who won't become engineers is to demystify technology." (Faculty, Chemical Engineering, interview)
- "First of all, I really believe that those are fundamentally good bodies of knowledge for people to be aware of whether they are engineers or not." (Faculty, Mechanical Engineering, interview)
- "An equally good outcome is people that are aware of [engineering]. It's being better able as citizens to understand issues related to technology." (Faculty, Mechanical Engineering, interview)

This commitment manifests in our project work through the inclusion of the Great Achievements and Grand Challenges of engineering as fundamental elements in the UTeach*Engineering* model high school curriculum, and pre-service and in-service professional development programs. Further, based on this commitment to engineering literacy, awareness of the impact of engineering on society was included as a key element of our primary outcome for engineering students and teachers: developing greater engineering awareness. Although we primarily seek to develop this awareness in engineering students and teachers, we are committed to designing our program and curricula to maximize influence beyond the immediate population of engineers and engineering teachers.

*Goals*

In categorizing our data, we differentiated between "goals" and "participant outcomes." The classification "goal" was assigned to statements or artifacts indicating what the project/program intended to accomplish, whereas "outcomes" referred to characteristics of the program product, the teachers participating in it, and ultimately their students. For example, the first goal, creating high school curriculum, is intended to result in students with certain knowledge and capabilities. The final versions of the themes related to goals of pre-college engineering and engineering teacher education are shown in Table 3, along with quotes that exemplify each theme.

As would be expected, the emergent themes for goals and outcomes largely mirrored the goals of the project as originally proposed to the NSF. There were, however, some changes, and some goals were retained only after substantial debate, revealing tensions arising naturally in a program requiring changes throughout the educational system. For example, the final goal indicated in Table 3, 'engineering for citizens', was strongly present in original project documentation, as well as some of the sources cited as warrants for those goals. As stated in the project proposal, "The goal is not that every student becomes an engineer, but rather that *all* students have opportunities to develop the design and interaction skills, as well as the preparation in Science, Technology, Engineering and Mathematics (STEM), that would enable them to be successful in an engineering career should they choose one, and that would enhance their lives and participation as global citizens even if they do not."

In member-checking discussions of the preliminary results of this study, however, project stakeholders struggled with how to balance resources and efforts between the needs of future engineers (e.g., exposure to authentic tools) with those of engineering literate citizens who would not go on to become engineers. This tension is reflected in the final exemplar quote under this theme in Table 3: "There's the obvious broad aspect which is to increase general awareness in the population but I would think the kind of [high school] curricular materials we are producing would be primarily for students who have an orientation in that direction [toward becoming engineers]." (Faculty, Mechanical Engineering, interview). Thus, while engineering for citizens (those not choosing to become professional engineers) was reaffirmed as an appropriate goal of UTeach*Engineering*, the high school course itself is primarily designed for future engineers. Engineering literacy, as described above, remains a commitment of UTeach*Engineering*; however, informing all its teacher preparation and curriculum development. Engineering literacy for pre-service teachers who do not plan to teach engineering is a major goal of UTeach, and engineering professional development for non-engineering teachers remains the top priority of the DTEACh program.

In contrast, the first goal, development of a model high school engineering course, did not appear among the original goals of the project as proposed to NSF. The original focus was, instead, on engineering teacher preparation. It was only after considerable reflection (and feedback) that the project embraced the notion that in order to prepare high school engineering teachers we must have a clear idea of what we expect them to teach, ultimately leading to the need for a well-characterized high school engineering course. The recognition that this course development must inform all the other components of the project ultimately led to model-course development as the first goal. This ordering indicates that it serves as a precursor to the other goals. Broadly speaking, the development of (or identification of previously developed) pre-college engineering curriculum must align with teacher preparation.

Other goals were present in the original UTeach*Engineering* proposal but evolved in response to realities brought to light in its implementation. For example, the proposal stated that "a key goal of our project is to reach a diverse population of teachers (directly) and students (indirectly)." This theme was confirmed in interview and artifact data. One survey stated:

- "[My objective is to] recruit and admit to ESIT and MASEE programs teacher participants from a geographically distributed set of schools serving diverse student populations." (Staff, survey)

In stakeholder review of the study results, however, it became clear that, although increasing the diversity in engineering was a critical commitment on the part of all of the participants, a precursor goal was to research and employ best practices as identified in previous research and experience for attracting and retaining engineering students and engineering teachers from underrepresented groups. This represents a paradigm shift from making assumptions about what might attract and retain participants to treating this as a question for exploration.

This shift in perspective arose from the acknowledgement that although much research has shed light on these practices, and those results should inform our practice: "The best we can do now is choose interventions based on guesses that are somewhat informed by the research, but they are still guesses" (Sanders, 2010, p.105). In other words, we are not yet certain what will increase diversity in engineering but are, instead, positioned to create curricula, based on prior experience and research, that are designed with this aim in mind and intended to enhance the state of understanding in this regard. The stance is articulated in this quote from the discussion at a team meeting:

- "I don't think in the time scale we have we can actually commit to attracting and retaining more students from diverse backgrounds…but I think what we can commit to, and do commit to, is in the development of all our programs, high school curriculum, in-service, pre-service, we aim to, we will aim to do this and will consult the current best

Table 3
Goals of Pre-College Engineering Education and Teacher Education

| |
|---|
| Develop a model high school engineering course with modular curriculum materials based on design challenges that may be implemented in other contexts, prioritizing strategies for success with students from historically underrepresented populations |
| • “[An objective is to] develop, pilot, and refine an exceptional year-long high school engineering course that can be deployed at low cost in a variety of high school settings.” (Project staff, survey) |
| • “[O]ne of [the in-service teachers] who had been the most opposed to the idea of challenges in the beginning was like, oh wait, now I see why we want to put a real problem around the front of it to give it a context for the whole thing.” (Project faculty, STEM Education, interview) |
| • “We introduce each module with a design challenge. So it’s all framed around ‘How are we going to solve this problem?’” (Project faculty, Chemical Engineering, interview) |
| • “[The challenge-based curriculum is] based on our understanding of the research that shows...that women and minorities are more interested in problems that deal with societal issues. Have broader impact…” (Project faculty, Mechanical Engineering, interview) |
| • “Because engineering gets done in teams, that’s a part of …what we’ll do with these courses.” (Project faculty, Chemical Engineering, interview) |
| Increase the number of high school teachers trained in engineering content (design) and engineering teaching knowledge using design based research, prioritizing strategies for attracting and retaining teachers from historically underrepresented populations |
| • “Equip teachers with sufficiently sophisticated engineering content knowledge to enable them to lead a secondary-level course.” (Project staff, survey) |
| • “Supporting teachers that may not have a very strong background in design.” (Project faculty, Chemical Engineering, interview) |
| • “[What we’re trying to see is] is this really in there, doing those iterative cycles of design based research [on professional development]…” (Project faculty, STEM Education, interview) |
| • “I started that mentoring program in the context of providing follow up for teachers who had been through the summer program. […]Hopefully, this kind of follow up will be quite empowering as they go on through their careers.” (Project faculty, Biomedical Engineering, interview) |
| Create viable and prestigious pathways within the university curriculum for high school engineering teacher certification, providing access for diverse candidates. |
| • “The other one that I worry about is whether or not the engineering community…will begin to embrace the idea of engineers…of engineering education as an important pathway in our [field].” (Project faculty, Chemical Engineering, interview) |
| • “One main thread is…. How do we create pathways within university curriculum so that people can become [engineering teachers]?” (Project faculty, Chemical Engineering, interview) |
| • “[An objective is to] Develop high-quality courses and curricula for the undergraduate courses. (To my mind, this should include the development of new courses in engineering as well as the revisiting/revising of existing courses in education to include engineering [STEM] in a meaningful way, which I think is nontrivial.)” (Project staff, survey) |
| Perform research and evaluation on challenge-based instruction, engineering teaching knowledge, and strategies for attracting and retaining traditionally underrepresented students and teachers in STEM education |
| • “...to me top, is to do research that contributes, that uses this unique opportunity of having high school engineering in [STATE], creating the curriculum for it, creating curriculum for teachers who will teach it, [] we have the HS teachers who will be teaching it, the HS students, so to use that very unique context to deliver results on what is learning in engineering that we can’t really answer in any other context.” (Project faculty, STEM Education, interview) |
| • “[We’ll use] best practices given the current state of knowledge and we’re going to advance the state of knowledge by examining those practices and their effects.” (Team meeting) |
| • “A key research question is to understand the impact our programs have had on attracting and retaining [more students from diverse backgrounds].” (Team meeting) |
| Disseminate research results and program practices |
| • “[My primary goal is to] increase the research base in the field on engineering education.” [Project faculty, STEM Education, survey] |
| • “We have also tried in the group to spend a lot of time and come up with a model of design and actually get it on paper and to the printers and get it published.” (Project faculty, STEM Education, interview) |
| Build collaboration and partnerships between schools and colleges on the university campus, between teacher preparation sites, and between universities, school districts and educational organizations at other levels |
| • “Build partnerships with school districts and replication sites that will enable schools across STATE to offer high-quality engineering courses.”(Project staff, survey) |
| • “That was one of the goals of the MSP, to actually have that partnership.” (Project faculty, Mechanical Engineering, interview) |
| • “[A primary goal is] collaboration with engineering faculty, [school district] teachers, and [ ] administration” (Project Faculty, STEM Education, survey) |
| • “Give engineers productive outlets to interact with K-12 schools” (Project faculty, Physics, survey) |
| Promote engineering for citizens. |
| • “This is something that can impact the way we think about things as citizens, on the way we think about problems in our daily lives.” (Project faculty, Chemical Engineering, interview) |
| • “With this high school engineering I don’t think my number one goal is necessarily to get more students interested in pursuing engineering. It’s a goal. But I also want students to come out of the class with a better awareness of the place that technology has in our society. They will be able to make better decisions as citizens.”(Project faculty, Mechanical Engineering, interview) |
| • “There’s the obvious broad aspect which is to increase general awareness in the population but I would think the kind of curricular materials we are producing would be primarily for students who have an orientation in that direction [toward becoming engineers].” (Project faculty, Mechanical Engineering, interview) |

research on how to create programs that attract and retain traditionally underrepresented students and teachers in STEM." (Team meeting)

As such, the goal of increasing diversity in engineering education was removed from our list of project goals. While it remains a firm hope of our project team—and a focus of our curriculum development approach—it is not a feasible goal for a project of this scope. Key evidence informing this shift resulted from the pilot implementation of a unit, which involved reverse engineering of a hair dryer. This activity had been chosen expressly for its perceived relevance to female students and earlier success in engaging female teachers (primarily at the elementary level) as part of professional development activities Participants in DTEACh program, in particular, had reported that they liked the hair dryer as it was a familiar example, a context in which they felt themselves to be experts. In contrast, during the pilot implementation of the activity as part of the high school curriculum, many participants were African American males, for whom the hair dryer held no particular interest, and who might have actually distanced themselves from the project based on perceived association with females. According to one discussion transcript:

- "Here's an example of what happened according to teachers recently in one of the focus groups: you develop a design challenge that is …hair dryers because you think you might interest girls and what do you find is… African American boys aren't using hair dryers, so the relevancy failed apparently… So you're stumbling through the practices." (Team meeting)

Despite our efforts, informed by our previous experiences, this challenge did not appeal to all the UTeach*Engineering* high school students and particularly alienated a group of students we had been hoping to attract. This incident was a reminder that even the selection of the hair dryer example based on previous interactions might serve to perpetuate a gender stereotype, bringing home the fact that the engineering education community is still not in a position to know with certainty what strategies will bring about an increase in diversity in the field with great certainty. Care will need to taken to identify design challenges that will motivate students in a given context. More research is needed and thus we have identified that as a goal.

"Science and mathematics learning" was another theme that was debated with regard to whether it was, in and of itself, a goal of UTeach*Engineering*. Historically, pre-college engineering outreach at the University of Texas has focused on engineering as a mechanism for learning mathematics and science. The DTEACh program, for example, was designed to help pre-college teachers incorporate design challenges into their mathematics and science instruction. As noted earlier, engineering rarely has a place in the standard curriculum and more often has been, instead, a component of more accepted mathematics and science courses. Many teachers participating in UTeach*Engineering* will ultimately teach more traditional mathematics or science courses in addition to, or possibly instead of, engineering. Thus, science and mathematics learning goals were naturally identified explicitly in many of the interviews, as illustrated here:

- "Students learn about mechanical, thermodynamics, fluid, electrical, and control systems." (Faculty, STEM Education, survey)
- "And if you don't have math and science, you're missing an opportunity… [w]hich is one of the main points of doing engineering is to provide context for learning the math and science." (Faculty, Mechanical Engineering, interview)

Ultimately, as a result of the growing emphasis on engineering and engineering design as learning goals in and of themselves, the project team chose to remove mathematics and science learning from our project goals. UTeach*Engineering*'s main goal is more accurately characterized as using science and math as tools to solve engineering challenges rather than the more traditional focus of using engineering as tool to teach science and math. Within this framing of our focus, there remains an expectation that mathematics and science understanding will be enhanced in this process and mathematical and scientific rigor is viewed as a fundamental component of engineering design:

- "That's what makes the high school [engineering] class a science class. If you are not doing structured design [you are not really doing engineering]." (Faculty, Mechanical Engineering, interview)
- "Predictions of performance, whatever, that builds on math and science. That's what engineers do. We want to show teachers that too." (Faculty, Mechanical Engineering, interview)

### *Engineering Student and Teacher Outcomes*

Learning outcomes for the high school students and in-/pre-service teachers in the program were also repeatedly identified in interviews and in project documents. The program goals were developed with these end outcomes in mind. For example, developing high school curriculum is a goal, not because it is an end unto itself, but rather as the vehicle for producing students with certain knowledge, skills, and characteristics. The production of students with the desired characteristics will be the criterion for whether the goal has been met in the right way. Desired outcomes for engineering students and engineering teacher candidates that arose from our analysis are given in Table 4.

These expected outcomes for engineering students and teachers are not unique to UTeach*Engineering*; in fact, many interviewees cited being directly influenced by other sources, e.g., NAE and NRC Committee on Engineering in K-12 Education (2009), as well as ABET and other standards. However, the fact that we see convergence among desired outcomes for engineering students and teachers on the part of UTeach*Engineering* and other key players in engineering education points to progress toward the identification of core ideas in engineering called for by the NAE's Committee on Standards in K-12 Engineering Education (2010).

Comparing our goals/outcomes to those identified in the NAE committee's Annex: Core Engineering Concepts, Skills, and Dispositions for K–12 Education (p.35), we find strong agreement with the elements most often identified in the literature surveyed: design ("Participants understand and can use the design process"); connections to Science, Technology, Mathematics (STM), although the UTeach*Engineering* treatment of this core idea as a connecting thread rather than a goal may differ from those reported in the Annex; engineering and society (included under "Participants develop greater awareness of engineering"); constraints (the UTeach*Engineering* design process,

Table 4
Outcomes for Engineering Students and Teachers

Students and teachers have greater awareness of engineering.
- "[We want to] give the students in these classes a sense of what it is that engineers do." (Project faculty, Chemical Engineering, interview)
- "An equally good outcome is people that are aware of [engineering]. It's being better able as citizens to understanding issues related to technology and to not be afraid of it." (Project faculty, Mechanical Engineering, interview)

Students and teachers exhibit "engineering habits of mind"
- *Problem solving approaches*
  - "[Get students to think about] What constraints do we have and how do we quantify those constraints, how do we make them measurable, make them testable." (Project faculty, Chemical Engineering, interview]
  - "We do try and give them systematic methods for [generating ideas]. One of the easiest for me to articulate is just reverse engineering." (Project faculty, Chemical Engineering, interview)
  - "Thinking about the different levels of the design problem is something that we want to embed in our [students] … in the way that we approach things." (Project faculty, Chemical Engineering, interview)
  - "There's other aspects of it too that are…decomposing a complex problem into simpler sub-problems." (Project faculty, Mechanical Engineering, interview)
  - "There's an aspect of optimization too. Do the most with the least." (Project faculty, Mechanical Engineering, interview)
  - "Here's what engineers do: We develop math models. We analyze designs with those models." (Project faculty, Mechanical Engineering, interview)
  - "The main goal is to think like an engineer (make decisions in the face of uncertainty, know what is 'good enough', employ creativity), not learn particular skills or tools." (Project faculty, Mechanical Engineering, interview)
- *Appreciation for diversity, communication and collaboration*
  - "If you are systematically thinking how can I get a different view point ... Gee I need somebody on my team who is … that's got this set of skills that is outside the box, that will ask these questions … that may not be able to contribute in other ways but will give that creativity by thinking outside the box." (Project faculty, Chemical Engineering, interview)
  - "Students understand that engineers work in teams (and that this is not generally a profession that leads to individual recognition)." (Project staff, survey)
  - "Because engineering gets done in teams, that's a part of …what we'll do with these courses." (Project faculty, Chemical Engineering, interview)
- *Affective characteristics: tolerance for uncertainty, ethical behavior*
  - "A common theme will be [in the face of failure], well, cycle back and do it again. You learned something." (Project faculty, Chemical Engineering, interview)
  - "You can teach techniques [for innovation] and then you practice, flex the muscle. People tend to not think of themselves as creative, but we're all creative." (Project faculty, Mechanical Engineering, interview)
  - "Problem solving as an engineer is actually very optimistic …You don't go into any problem thinking well, this is going to be hard, there's not gonna be a solution." (Project faculty, Mechanical Engineering, interview)
  - "[Another goal is] to have an understanding of what the ethical responsibilities are of engineers." (Project faculty, Chemical Engineering, interview)

Students understand and can use the engineering design process
- "And it's got all kinds of challenges embedded in it of identifying what is the problem, and then how can that problem be solved using engineering tools for analysis and design." (Project faculty, Biomedical Engineering, interview)
- "Design … implies that there's an open ended aspect of it. A design problem to me includes an ability to do synthesis—to generate alternatives and choose from among those alternatives … synthesizing alternatives." (Project faculty, Mechanical Engineering, interview)
- "This design cycle… . Lots of different names for it. Lots of different ways of expressing it, those elements … but going through that design cycle is how we are approaching this." (Project faculty, Chemical engineering, interview)

In-service and pre-service teachers demonstrate enhanced capacity for engineering teaching
- "Teachers demonstrate greater capability to effectively teach and/or incorporate engineering content and design principles into their classes." (Project staff, survey)
- "Preparing teachers to have that degree of flexibility." (Project faculty, Chemical Engineering, interview)
- "I think it would be a disservice to the teachers if we don't teach anything related to pedagogy." (Project faculty, Mechanical Engineering, interview)
- "I think we should be teaching our teachers of engineering, to the extent that we can, how to think like an engineer. How to decide whether a design project that we haven't come up with is a good one for their students." (Project faculty, Mechanical Engineering, interview)

included as a strategy under "Participants understand and can use the design process") emphasizes consideration of customer needs, specifications and constraints explicitly; and communication ("Participants develop engineering habits of mind.") The Annex lists innovation (cited by only one of the references surveyed) and creativity (cited by three references) separately. The UTeach*Engineering* project conceives of innovation as an activity arising from creativity, which we include as an engineering habit of mind, and a ubiquitous theme in our program.

All of the core ideas that appear more than twice in the Annex (and some that occur less often, such as systems thinking) are clearly identified in goals and outcomes for the program, with the exception of "knowledge of specific technologies." Although "Provide opportunities for students to use realistic engineering tools and techniques common in industry" is a core UTeach*Engineering* strategy, the program has chosen not to endorse particular technologies in favor of general techniques.

Many of the student outcomes listed under ABET's General Criterion #3 also align with the expected outcomes we have identified for students and teachers, particularly those associated with engineering habits of mind (ABET, n.d.). For example, it is our expectation that students leaving pre-college engineering education will have already begun to demonstrate "an ability to apply knowledge of mathematics, science, and engineering" (outcome a) and "to design and conduct experiments, as well as to analyze and interpret data" (b). They will have demonstrated the ability to "identify, formulate and solve engineering problems" (e), "design a system, component, or process to meet desired needs within realistic constraints" (c), "function on multidisciplinary teams" (d), and "communicate effectively" (g). Finally, they should have exposure to "techniques, skills, and modern engineering tools necessary for engineering practice" (k).

In summary, there is good agreement among the core ideas identified as having the most support from the sources surveyed in the Committee on Standards in K-12 Engineering Education (2010) Annex, those identified by ABET, and those identified by UTeach*Engineering*. This points toward a growing consensus in the engineering education community on what our programs hope to achieve and our students should be able to do and the possibility that we will soon be able to develop standards for pre-college engineering education.

*Summary*

The commitments, goals, and expected outcomes for pre-college engineering education we identified, as well as the relationship between them, are represented in Figure 1. This diagram indicates the way in which the commitments embraced by UTeach*Engineering* give rise to goals for K-12 engineering education, and the way those goals give rise to engineering student and teacher outcomes.

Although certain commitments give rise more directly to certain goals, all of the commitments are expected to inform all of the goals, as well as the strategies designed to address them. For example, increasing diversity among pre-college engineering students and teachers is not separated into a single goal; rather our commitment to equity is a driver that determines the nature of the curriculum we will develop and the training our teachers will receive, sets requirements for the certification pathways we create, informs our research and evaluation, and so on.

In a similar manner, the commitment to research, i.e., application and continuous refinement of best practices,

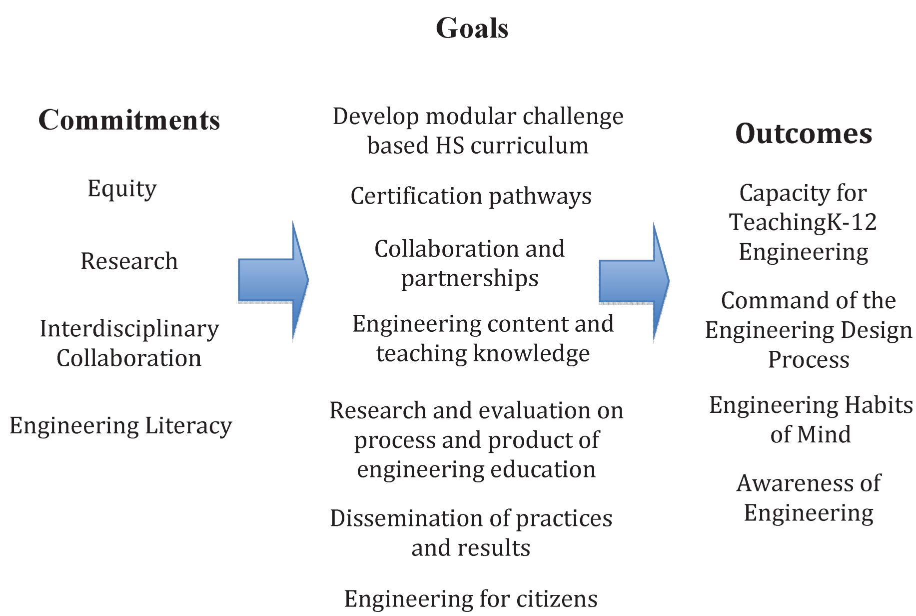


**Figure 1.** Schematic vision of pre-college engineering education

informs all the goals, not just the goals of performing and disseminating research. The commitment to engineering practice drives the nature of project curriculum and teacher preparation. The commitment to interdisciplinary collaboration informs who should develop curriculum and prepare teachers, as well as the nature of certification pathways, and the structure of research teams. Engineering literacy speaks to the importance of engineering for citizens in our curriculum and teacher preparation and the importance engineering habits of mind among the outcomes for all students, regardless of whether they will become engineers.

## Conclusions

We began the paper reiterating a need for a clear vision of pre-college education – for work helping the education and research communities understand the goals and approaches for teaching engineering at the pre-college level. Figure 1 illustrates UTeach*Engineering*'s proposal for addressing this need.

For example, this work posits that that a primary goal of pre-college engineering education is for students to develop a command of the engineering design process and engineering habits of mind and that traditional math and science content goals are secondary to this in an engineering class. This is an important commitment. As policy documents increasingly emphasize engineering learning goals (National Academy of Engineering Committee on Standards in K-12 Engineering Education, 2010), we must consider carefully when and how these are being addressed. Our contention is that they cannot be a side-note in traditional math and science classes. In addition, we posit that engineering teachers must share this expertise, which suggests a need for more programs, like ours, to certify teachers to teach engineering. Engineering is no longer a course that can be unproblematically added to the schedule of a math or science teacher that has had no additional training.

While we do not espouse these goals, commitments, and learning outcomes as the final answer to the questions surrounding the engineering education community's development of a shared vision of pre-college engineering education, we offer them as a proposal for discussion, with the hope that further discussions will result in a shared understanding in how we will define engineering education for pre-college students as we move forward. Beyond the establishment of this common vision, further work will also be required to validate approaches and strategies to meet the goals thus articulated.

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